Chapter 7

Impacts of Sea-Level Rise on Coastal Landscapes

Enrique Reyes, University of New Orleans, Department of Geology and Geophysics, New Orleans, LA70148; **Jay F. Martin**, Department of Food, Agricultural, and Biological Engineering, Ohio State University; **John W. Day**, Coastal Ecology Institute and Department of Oceanography and Coastal Sciences, LSU; **G. Paul Kemp**, Special Programs, School of the Coast and Environment; and **Hassan Mashriqui**, Special Programs, School of the Coast and Environment.

Summary

Two landscape explicit models were used to investigate habitat shifts in coastal Louisiana due to varying river forcing and sea-level rise. Land loss and yearly shifts of marsh habitats in two contrasting watersheds were examined, one a prograding and the other a regressive delta. The models linked several modules dynamically across spatial and temporal scales. Both models consisted of 3 coupled modules: a vertically integrated hydrodynamic module; a process-based biological module of above and below ground primary productivity; and a module for soil dynamics. The models explored future effects of possible sea-level rise and river diversion plans for a 30-year and a 70-year projection starting in 1988. Results suggested that increased river forcing (flow) had large land preservation impacts, and healthy functioning of the Mississippi Delta depends largely on freshwater inputs. This type of model is a useful tool for research and management for predicting causes and effects of regional impacts and structural landscape level changes.

7.1 Introduction

The Mississippi River is the source of sediment for most of the Louisiana coastal marshes. This contribution serves to maintain and create coastal marsh habitats. Opposite to this process, and since the beginning of the 20th century, natural processes, such as subsidence and sea-level rise, in combination with human activities including canal dredging, sediment diversion and extensive levee construction along the Mississippi River have overturned the natural balance. To date, the river now funnels sediments over the continental shelf and no longer contributes to the coastal areas. Coastal wetlands across southeastern

Louisiana have contracted and are being lost as they are converted to open water (Wells, 1996), serving as models for the effects of accelerated sea-level rise (Day and Templet, 1989). Annual variability in mean sea-level (MSL) can be several centimeters per year (Baumann, 1980), and high MSL can result in increased penetration of salinity into wetlands (Penland et al., 1988). Wetlands naturally sink as the soft sediments deposited on them by rivers consolidate and compress under their own weight. Such changes are believed to underlie the general pattern of displacement of freshwater vegetation by more salinity tolerant communities, and vegetation die-off followed by conversion to open water (Wells, 1996; Roberts, 1997). In contrast, active sediment deposition when associated with river discharge leads to land progradation (Roberts, 1997). An example of this active land building can be found in the Atchafalaya delta at the mouth of the Atchafalaya River (Fig. 1).

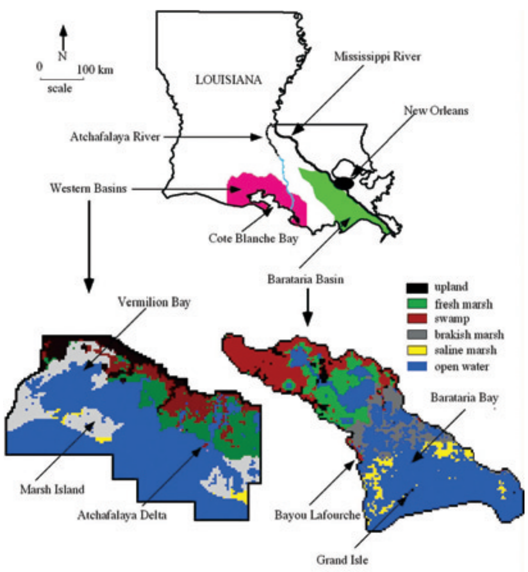

Figure 1. The State of Louisiana showing location for the Barataria and Western Basins.

Most wetlands in the Mississippi Delta estuarine complex are losing elevation to MSL at variable rates (Penland and Ramsey, 1990). These rates vary not only spatially but also temporally. We present two contrasting regions: the Barataria Basin and the watershed comprised by the Vermilion, Cote Blanche Bays, and the Atchafalaya delta, here defined as the Western Basins (Fig. 1). Calculated mean annual land loss rates in Barataria and the Western Basins for three different periods are presented in table 1, with a mean for all periods of 57.3 km^2 and 10.68 km^2, respectively (Britsch and Dunbar, 1993). Reed (1995) estimated that indirect land loss due to canal dredging alone could account for more than 30% in the Barataria Basin. This finding indicates that local anthropogenic modifications have had different effects in each basin making it difficult to assess changes on a regional basis.

Understanding these land loss rates and impacts (e.g. habitat change) is critical for assessing the long-term effects of evolving forcing functions (e.g., river discharge) to restoration approaches. The objectives of this study were to (1) construct a multiple scale process model for the Barataria and the Western Basins to understand and predict regional habitat change; and (2) assess wetland response to long-term indirect and cumulative impacts of different river forcing.

To address these issues we used spatially articulated landscape models under diverse scenarios (Sklar et al., 1985; Costanza et al., 1990; White, 1991; White et al., 1991; Reyes et al., 1994; Martin et al., 2000; Reyes et al., 2000). These dynamic spatial interaction models incorporate location specific algorithms that allow feedback between the local processes and the landscape dynamics, so that both the landscape and the intensity of the processes affecting it change throughout time (Boumans and Sklar, 1990). In this chapter we present the results of varying the environmental functions, namely river discharge and rates of sea-level rise, and the effects of those variations on two different watersheds.

7.2 Study Area

The Barataria estuarine system is an estuarine-wetland system located between the natural levees of the Mississippi River and Bayou Lafourche. It is roughly triangular in shape with an area of 6100 km2. The Western Basins are bordered by Freshwater Bayou on the west and the Atchafalaya River on the east and occupies about 6765 km^2 (Fig. 1).

Both basins are dynamic systems undergoing change due to natural and human processes. The Barataria basin has been closed to direct river inflow since 1904. Precipitation provides its main source of freshwater; however, the Mississippi River exerts an indirect influence on salinity in the lower basin by reducing salinity in the nearshore Gulf of Mexico (Perret et al., 1971). The Western Bays basins are directly influenced by the Atchafalaya River (Penland and Ramsey, 1990). As a result, these basins are examples of the few locations in southern Louisiana that have experienced net land gain (Boesch et al., 1994).

7.3 Methods

A landscape habitat prediction model was built for each watershed. Each is a dynamic spatial model under variable time and spatial scales, using a finite difference, 2-dimensional and vertically integrated hydrologic module coupled with a primary productivity module. Output from the hydrodynamic and productivity modules are submitted to a soil module and then evaluated by a habitat switching module that redefines the habitat mosaic on a biannual basis. Specific details for the modules and their interactions have been documented previously (White et al., 1997; Martin, 2000; Reyes et al., 2000).

Forcing functions to the models consist of an historical data series spanning 1956 through 1995 that include climatic variables (precipitation, wind, temperature), river flow and sediment concentration, relative sea-level rise (RSLR-comprised of subsidence and eustatic sea-level rise), tides, and salinity.

7.4 Calibration

Both models were calibrated by comparing results against historical conditions. The models were run for the 1978 to 1987 decade using habitat classified maps prepared by U.S. Fisheries & Wildlife Service (USFWS) to set initial conditions and final spatial comparison. This calibration exercise examined how much the simulated ecological processes across the landscape compensate for all the land loss processes implicit in the real landscape dynamics. Large scale dynamics, as the ones performed by this landscape model, do not explicitly incorporate local processes (e.g., effects of small canals and spoilbanks), however the calibration of regional parameters incorporates whatever regional effects these local processes might have.

The landscape calibration required a match in habitat distribution. The resulting habitat classified maps are presented in Figure 2 for both the Barataria Basin Model (BBM) and the Western Basins Model (WBM). A useful estimate of habitat agreement can be calculated as the percentage of change of the total wetland area (i.e., the sum of marshes and swamp habitats). These values are 3% for BBM and 2% for WBM, however these percentages don't take in to consideration the spatial agreement nor the different habitat types. Thus, for the agreement between each of the two simulated maps to be quantified, we used a goodness-of-fit, a spatial statistics routine comparing the spatial pattern of habitat cells at multiple

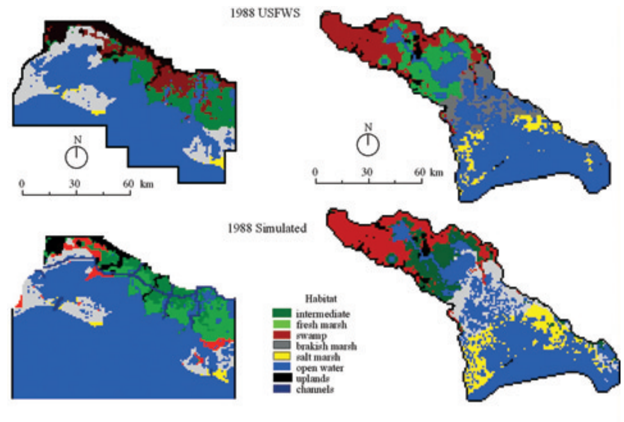

Figure 2. Habitat classified USFWS maps for 1988 and resulting maps from the calibration exercise.

resolutions (Costanza, 1989), which gave a value above 85 for both basins (Martin, 2000; Reyes et al., 2000) out of a possible 100, where 0 is no match to 100 is a perfect match.

7.5 Sea-level Rise and River Discharge Scenarios

Landscape models of this type are one of the few tools that can be used to predict the effects of complex spatial interactions and cumulative, long-term effects of global changes. Simulations, from 1988 to 2018, were performed for a series of scenarios (Table 2). The first scenario, referred to as Normal Conditions (NC), simulated a future continuation of current trends. Later simulations are evaluated by comparing results against this NC scenario.

7.5.1. Normal Conditions Scenario

The NC scenario consisted of a 30-year simulation for each basin (a 70-year prediction is also presented for the WBM). To run simulations into the future, theoretical time series and boundary conditions need to be selected. We repeated the original time series in reverse order, because climate tends to be cyclic (Thomson 1995). The forcing functions and boundary conditions are actual data for years 1955 – 1992, but when the year 1993 was simulated, the climate from 1991 was used, 1994 simulation used climate from 1990, and so on.

The resulting habitat distribution for the BBM (Fig. 3) converted 1,105 km^2 to open water during 1988 to 2018 (Table 2) or about a loss of 48% total wetland area. The largest decline (498 km^2) was for brackish marsh, while only 5 km^2 of swamp were lost. The model identified large portions of the mid-

Table 1 Annual loss rates (km^2) for three different periods in the Western Bays and Barataria Basins.

Interval	Western Bays km^2 yr-1			Barataria km^2 yr-1		
1931-1958	2.41			7		
1956-1978	3.41[a]	3.3		16[a]	21.55	25.50
1978-1988	2.57[b]	4.4	0.8	19[b]	35.40	27.11
Source:	(Britsch and Dunbar 1993)	USFWS	Model output	(Dunbar et al. 1992)	USFWS	Model output

Note: [a]1956-74 and [b]1983-1990 intervals.

Table 2 Summary of scenario results performed in each basin.

Resulting Habitat Coverage (km^2)

Scenario Name	Intermediate Marsh	Fresh Marsh	Swamp	Brackish Marsh	Salt Marsh	Open Water	Calibration Fit
Western Basins 1988 USWFS map	219	727	461	674	76	6465	
Calibration (1977-87)	238	737	462	701	77	6407	94.93
Normal Conditions (1988-2018)	172	1185	462	442	55	6306	
(1988-2058)	300	1383	461	152	58	6268	
High River Forcing (1988-2018)	302	1588	468	110	22	6132	88.64
(1988-2058)	216	1793	462	79	30	6042	86.84
No River Forcing (1988-2018)	289	1159	465	301	53	6355	92.39
(1988-2058)	225	1264	460	50	58	6565	89.25
Twice SLR rate (1988-2018)	289	1264	465	196	53	6355	91.67
(1988-2058)	225	1263	460	50	58	6566	88.06
Barataria Basin 1988 USWFS map		755	1022	734	460	2952	
Calibration (1977-87)		723	1002	722	634	2854	89.32
Normal Conditions (1988-2018)		396	1017	236	217	4057	
High River Forcing (1988-2018)		1022	1022	293	159	3427	85.63
Low River (1988-2018)		612	1022	567	389	3335	76.74
Twice SLR rate (1988-2018)		240	1014	150	200	4319	94.77

Notes: USWFS = U.S. Wildlife & Fisheries Service; SLR = sea-level rise. Fit values for Base Case scenarios were computed against 1988 USWFS habitat map. Fit values for river forcing options were computed against the 2018 normal conditions habitat map.

dle and lower brackish marsh that converted to open water, whereas the upper basin, dominated by swamp habitat, remained relatively unchanged. The land change in the middle basin was due to increased water levels and a diminishing plant productivity while the lower basin suffered from rising sea-level and increased salinity.

The WBM study area experienced a 7.37% gain in wetland during the 30-year NC (9.13% for the 70-year run) which was due to the expansion of freshwater marsh coverage (458 km^2) associated with the progradation of the Atchafalaya Delta (Fig. 3, Table 2). The areas around the Atchafalaya Delta sustained their original habitat, in contrast with areas that started to break up such as the ocean side of Marsh Island. Although only 30% of the Mississippi River discharge was used as flow for the Atchafalaya River (nominal U.S. Army Corps of Engineers discharge values), the capacity of this forcing to deposit sediments resulted in a noticeable delta growth.

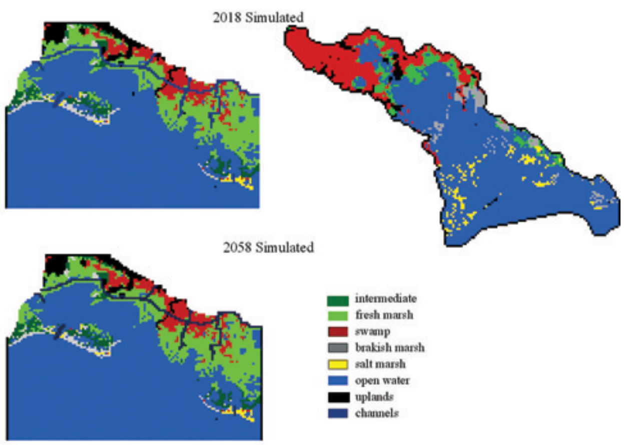

Figure 3. Resulting habitat distribution of Western and Barataria Basins under the Normal Conditions scenario for years 2018 and 2058.

7.5.2 Additional River Discharge Scenario

This scenario simulated a two-fold increase of river water into the basins. Under a global warming scenario, the discharge from the Mississippi has been computed to increase as a direct result of modifications to the hydrologic cycle such as increased precipitation (Justic et al., 1996). Based on these studies and the possibility of increased water flow through river structures and land runoff, we considered this a plausible scenario.

For the BBM, the main inflow was through the southeastern boundary, as the Mississippi River discharges into the Gulf. A smaller percentage of the input water, however, gets delivered through the West Point la Hache and Namoi siphons (i.e., water pumps). Land loss in this scenario was 630 km^2 less than the NC (Fig. 4). The overall change was gain of 33 % for the wetlands. The freshwater marsh had the least losses (626 km^2 were preserved), in contrast to salt marsh which showed a 27% decline (58 km^2 loss) from the NC scenario (Table 2).

Historically, the Atchafalaya River discharge has gone from unimportant to about 30% of the total flow of the Mississippi and Red rivers over the past two centuries (Roberts 1997). This increased discharge now is coupled with efforts to control the flow of the Mississippi River. Simulations for the WBM, using twice the Atchafalaya River discharge, increased both, the water and sediment delivered to the estuary, and increased the growth of the deltas by 174 km^2 compared to the NC for 2018 and by 226 km2 for 2058 (Fig. 4). By doubling river input brackish and salt marshes were subject to freshwater influence. This freshening of the habitat resulted in a transformation of 506 km^2 into a combination of intermediate freshwater marsh and open water across the study area (Table 2).

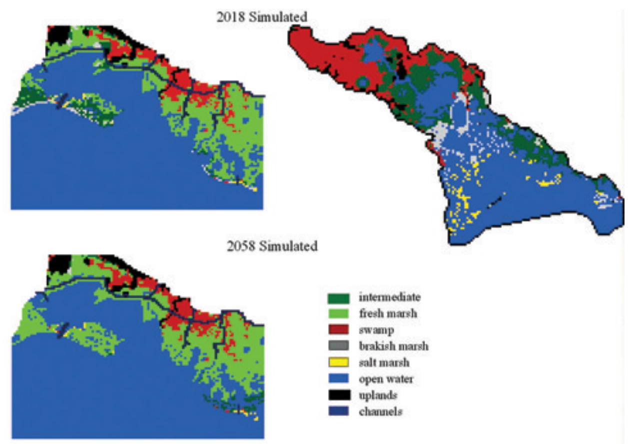

Figure 4. Resulting habitat distribution of Western and Barataria Basins under the high river discharge scenario for years 2018 and 2058.

7.5.3 Restricted River Discharge Scenario

A restriction of river inputs is exemplified by the current situation in the Barataria basin. Since 1904 the Barataria basin has been isolated from river inflow. However, presently in addition to restricted river inputs other factors such as, oil and gas exploration, salt water intrusion, and weirs and locks affect the wetland functioning (Condrey et al., 1995). For an increased restriction of river discharge scenario in this basin, a low river discharge year (1964) was used. The results of this low-river scenario paint a complex picture (Fig. 5). A total of 722 km² of wetlands were preserved from the NC scenario, with 92 km² more than in the "Additional River" scenario. Most of these gains were in brackish marshes that almost doubled in extension (Table 2), showing, perhaps, a homogeneous influence of water conditions for all the landscape. That is, constant salinity influence and little flooding seem to favor salt tolerant communities.

The scenario for WBM comprised reducing the Atchafalaya River flow to one half normal discharge, resulting in decreased growth of the deltas and leading to increased land loss (Fig. 5). Habitat extension for 2018 is similar as in BBM, brackish and salt marsh extension is higher than with the Increased River Discharge scenario. This behavior, however, changes to substantial losses (about 300 km²; Table 2) for the year 2058. Elimination of river input increased land loss and salt intrusion to the area.

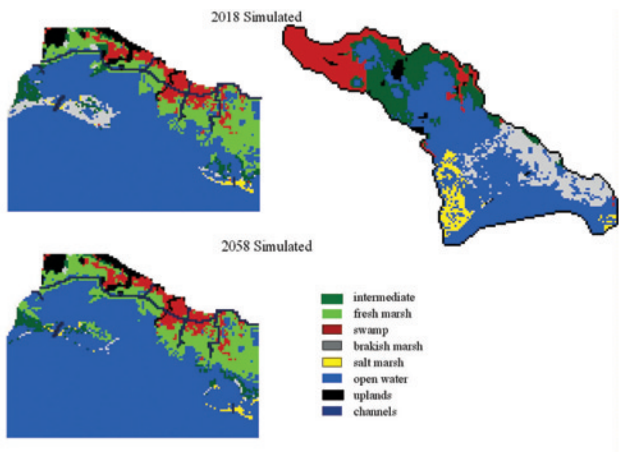

Figure 5. Resulting habitat distribution of Western Basins under no flow scenario and Barataria Basin under the low river flow scenario for years 2018 and 2058.

7.5.4 Increased Sea-Level Rise Scenario

Future scenarios of coastal areas must consider the possibility of an increased Sea-Level Rise (SLR) rate due to global climate change and/or increased subsidence. In the previous scenarios the SLR rate used was 0.18 cm/yr (an average for the values reported by Gornitz et al., 1982). The increased SLR scenario considered a rate of 0.4 cm/yr, double the standard rate, but well within the range of values calculated by several authors (Hoffman, 1984; Emery and Aubrey, 1991; Gornitz, 1995), and representative of the "best guess" rates estimated by the IPCC (Gornitz, 1995).

Increasing the SLR rate, for both watersheds, resulted in extensive losses of inland habitats (Table 2). While for Barataria the total land loss was of 262 km² by 2018, the Western Bays show a slower decline of 55 km² by 2018 and 298 km² by 2058. Presenting a clear image of the pernicious influence of saltwater intrusion in both basins (Fig. 6).

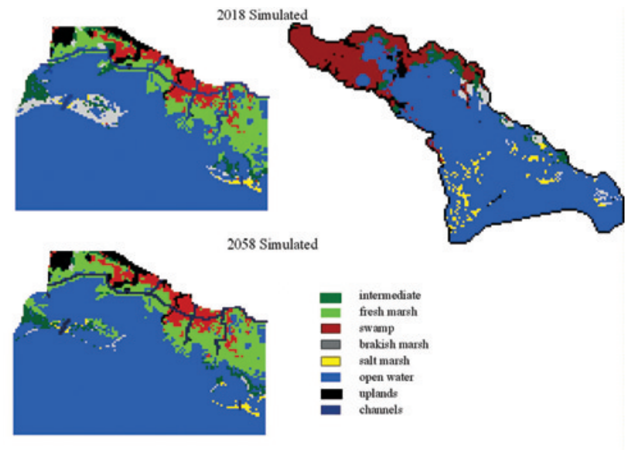

Figure 6. Resulting habitat distribution of Western and Barataria Basins under the double sea-level rise rate scenario for years 2018 and 2058.

Overall, fresh and brackish marshes lost from 30 to 50% of the area remaining in the Normal Conditions scenario. Salt marshes on Barataria basins decreased by 17 km². However, under the Additional River Discharge scenario, these salt marshes were the only habitat that expanded (an increase of 41 km².)

For the WBM, the same decreasing trend of marsh area can be observed when compared with the NC value (Fig. 6). By 2018 fresh marsh increased to 79 km² but at the end of the simulation this value becomes a net loss of 120 km². Salt marshes, however, keep the same coverage. When open water extension is compared with the Additional River Discharge scenario it becomes evident how accentuated the marsh loss can be (Table 2).

7.6 Discussion

The principal regional factors driving long-term trends in land-loss and habitat change in coastal Louisiana are (1) sea-level rise and subsidence, (2) changes in the introduction of freshwater and sediments from the Mississippi and Atchafalaya Rivers, and (3) modifications to internal hydrology (Gagliano et al., 1981; Baumann et al., 1986; Salinas et al., 1986; Coleman, 1988; Day and Templet, 1989; Boumans and Day, 1993; Reed, 1995; Day et al., 1997; Turner, 1997). Our landscape models are driven by these same dominant regional processes and were sensitive to factors that affect how land and water surfaces evolve interactively through time. This means the models are less sensitive to local human factors such as canal dredging or natural factors such as nutria destruction or fires.

Simulation results indicated the importance of river discharge forcing. Overall, increased river input to both basins resulted in net gains or preservation of marsh areas. Although the flow alterations presented here may seem extreme, they do have a historical and future relevance. Reductions in riverine inputs mimic trends that have taken place in the past, as the Barataria present conditions indicate. Increased river discharge is now occurring in the Western Bays area, as the Atchafalaya discharge has risen from minimal to 30% of that of the Mississippi River. Compounding these changes in river flow, the amount of sediments reaching the Mississippi is about 75% less than historical conditions due to natural and anthropogenic changes (Cahoon et al., 1995; Wells, 1996).

It was our intention to test the long-term effects of climate in both basins. As the climate conditions became more extreme (i.e., increased SLR scenario) habitats changed and overall land loss increased (Table 2). Relatively high rates of loss, on the order of 30 to 40 km^2/yr, are predicted for all river forcing scenarios. The comparisons of the variability of the fit indices in both basins (Table 2) suggest that Barataria is more susceptible to habitat changes (the range of values is larger) than the Western Bays marshes. The Western Bay marshes are currently influenced by flow of the Atchafalaya River, resulting in habitats more resistant to changes in weather and sea-level rise effects. Using the goodness-of-fit index as an indicator of beneficial processes was not straightforward. Lower values only indicate the amount of discrepancies between the resulting map and the NC scenario. Thus, both high and low river forcing scenarios had low values for both basins, in contrast with the high values for the increased SLR scenario. These values argue for the use of the fit number along with a visual interpretation of the resulting map to determine the net benefits of a management strategy. These results, along with the NC scenario, also indicate that weather might be responsible for the largest changes in marsh stability. Across basin processes such as, accretion, vegetation productivity and sediment inputs alone can not compensate for the effects of increased sea-level rise (as high as 10 cm interannually; Penland and Ramsey, 1990), acute weather conditions (hurricanes and winter storms), and natural subsidence (Baumann et al. 1986; Coleman, 1988; Day and Templet, 1989; Nyman et al., 1990; Cahoon, 1994; Wells, 1996).

7.7 Conclusions

Two dynamic landscape models for coastal Louisiana were developed to combine hydrodynamic and biological processes at different time and space scales. These mechanistic models included feedback among four different modules (water, soil, plant, and habitat switching) demonstrating the ability to accurately reproduce historical conditions and forecast the consequences of climate change scenarios.

River forcing scenario results demonstrated the importance of increasing water delivery and throughput into both basins. As these areas are subject to restricted freshwater inflows, the rate of land loss increases, but not necessarily in a linear fashion.

The use of these landscape models allows evaluation of natural processes across regions and investigation of cause and effect related to climate change scenarios at specific locations.

Acknowledgments

Financial support for this study was provided by the Barataria-Terrebonne National Estuary Program (BTNEP) through the LA. Department of Environmental Quality and the New Orleans District of the U.S. Army Corps of Engineers and the Gulf Coast regional climate change assessment project supported by the USEPA, through a subcontract with Southern University. The authors would like to acknowledge the assistance of the BTNEP and the WBM Scientific and Technical Committee members in reviewing early results. Our heartfelt thanks to Ms. Emily Hyfield for editing and proof-reading.

References

Baumann, R. H. 1980. Mechanisms for maintaining marsh elevation in a subsiding environment. Master's Thesis, Louisiana State University.

Baumann, R. H., J. W. Day, and C. A. Miller. 1986. Mississippi Deltaic Wetland Survival: Sedimentation Versus Coastal Submergence. Science 224: 1093-1095.

Boesch, D. F., M. N. Josselyn, A. J. Mehta, J. T. Morris, W. K. Nuttle, C. A. Simenstad, and D. J. P. Swift. 1994. Scientific assessment of coastal wetland loss, restoration and management in Louisiana, Special Issue No. 20 ed. Coastal Education and Research Foundation, Lawrence, Kansas.

Boumans, R. M. J., and J. W. Day. 1993. Effects of two Louisiana marsh management plans on water and material flux and short-term sedimentation. Wetlands 14: 247-261.

Boumans, R. M. J., and F. H. Sklar. 1990. A polygon-based spatial (PBS) model for simulating landscape change. Landscape Ecology 4: 83-97.

Britsch, L. D., and J. B. Dunbar. 1993. Land loss rates: Louisiana coastal plain. Journal of Coastal Resources 9: 324-338.

Cahoon, D. R. 1994. Recent accretion in two managed marsh impoundments in coastal Louisiana. Ecological Applications 4: 166-176.

Cahoon, D. R., D. J. Reed, and J. W. Day. 1995. Estimating Shallow Subsidence in Microtidal Salt Marshes of the Southeastern United States: Kaye and Barghoorn Revisited. Marine Geology 128: 1-9.

Coleman, J. M. 1988. Dynamic changes and processes in the Mississippi River delta. Geological Society of America Bulletin 100: 999-1015.

Condrey, R., P. Kemp, J. Visser, J. Gosselink, D. Lindstedt, E. Melancon, G. Peterson, and B. Thompson. 1995. Status, Trends, and Probable Causes of Change in Living Resources in the Barataria and Terrebonne Estuarine Systems, Barataria-Terrebonne National Estuary Program, Thibodaux, LA.

Costanza, R. 1989. Model Goodness of Fit: a multiple resolution procedure. Ecological Modelling 47: 199-215.

Costanza, R., F. H. Sklar, and M. L. White. 1990. Modeling Coastal Landscape Dynamics. BioScience 40: 91-107.

Day, J. W., J. F. Martin, L. C. Cardoch, and P. H. Templet. 1997. System functioning as a basis for sustainable management of deltaic ecosystems. Coastal Management 25: 115-153.

Day, J. W., and P. H. Templet. 1989. Consequences of sea-level Rise: implications from the Mississippi Delta. Coastal Management 17: 2411-257.

Dunbar, J. B., L. D. Britsch, and E. B. I. Kemp. 1992. Land Loss Rates; Report 3, Louisiana Coastal Plain. Report 3 of a series GL-90-2. United States Army Corps of Engineers. New Orleans.

Emery, K. O., and D. G. Aubrey. 1991. sea-levels, land levels and tide gauges. Springer-Verlag, New York.

Gagliano, S. M., K. J. Meyer-Arendt, and K. M. Wicker. 1981. Land loss in the Mississippi River deltaic plain. Transactions of the Gulf Coast Association of the Geological Society 31: 295-300.

Gornitz, V. 1995. Sea-level rise: a review of recent past and near-future trends. Earth Surface Processes and Landforms 20: 7-20.

Gornitz, V., S. Lebedeff, and J. Hansen. 1982. Global sea-level trend in the past century. Science 215: 1611-1614.

Hoffman, J. S. 1984. Estimates of Future sea-level Rise, p. 79-103. In J. C. T. M.C. Barth (ed.), Greenhouse Effect and sea-level Rise: a challenge for this generation. Van Nostrand Reinhold Co. The Hague.

Justić, D., N. N. Rabalais, and R. E. Turner. 1996. Effects of climate change on hypoxia in coastal waters: A doubled CO2 scenario for the northern Gulf of Mexico. Limnology and Oceanography 41: 992-1003.

Martin, J. F. 2000. Manipulations of natural system functions within the Mississippi Delta: A simulation-modeling study. Dissertation, Louisiana State University.

Martin, J. F., M. L. White, E. Reyes, G. P. Kemp, H. Mashriqui, and J. W. Day. 2000. Evaluation of Coastal Management Plans with a Spatial Model: Mississippi Delta, Louisiana, USA. Environmental Management 26: 117-129.

Nyman, J. A., R. D. DeLaune, and W. H. Patrick. 1990. Wetland soil formation in the rapidly subsiding Mississippi River deltaic plain mineral and organic matter relationships. Estuarine, Coastal and Shelf Science 30: 1-13.

Penland, S., R. Boyd, and J. R. Suter. 1988. Transgressive depositional systems of the Mississippi delta plain: a model for barrier shoreline and shelf sand development. Journal of Coastal Research 58: 932-949.

Penland, S., and K. E. Ramsey. 1990. Relative sea-Level rise in Louisiana and the Gulf of Mexico: 1908-1988. Journal of Coastal Research 6: 323-342.

Perret, W. S., B. B. Barret, W. R. Latapie, J. F. Pollard, W. R. Mock, G. B. Adkins, W. J. Gaidry, and C. J. White. 1971. Cooperative Gulf of Mexico estuarine inventory and study, p. 31-175. In Louisiana, Phase 1, area description. Wildlife and Fisheries Commission,

Reed, D. J. E. 1995. Status and Trends of Hydrologic Modification, Reduction in Sediment Availability, and Habitat Loss/Modification in the Barataria-Terrebonne Estuarine System. BTNEP No. 20. Barataria-Terrebonne National Estuary Program, Thibodaux, LA.

Reyes, E., J. W. Day, and F. H. Sklar. 1994. Ecosystem Models of Aquatic Primary Production and Fish Migration in Laguna de Terminos, Mexico, p. 519-536. In W. J. Mitsch (ed.), Global Wetlands: old world and new. Elsevier Scientific Publishers, Amsterdam.

Reyes, E., M. L. White, J. F. Martin, G. P. Kemp, J. W. Day, and V. Aravamuthan. 2000. Landscape Modeling of Coastal Habitat Change in the Mississippi Delta. Ecology 81: 2331-2349.

Roberts, H. H. 1997. Dynamic changes of the Holocene Mississippi River delta plain: the delta cycle. Journal of Coastal Research 13: 605-627.

Salinas, L. M., R. D. DeLaune, and W. H. Patrick Jr. 1986. Changes Occurring Along A Rapidly Submerging Coastal Area: Louisiana, USA. Journal of Coastal Research 2: 269-284.

Sklar, F. H., R. Costanza, and J. W. Day, Jr. 1985. Dynamic Spatial Simulation Modelling of Coastal Wetland Habitat Succession. Ecological Modelling 29: 261-281.

Thomson, D. J. 1995. The Seasons, Global Temperature, and Precession. Science 268: 59-68.

Turner, R. E. 1997. Wetland loss in the northern Gulf of Mexico: multiple working hypotheses. Estuaries 20: 1-13.

Wells, J. T. 1996. Subsidence, sea-level rise, and wetland loss in the lower Mississippi river delta, p. 281-311. In J. D. Milliman and B. U. Haq (eds.), Sea-level rise and coastal subsidence. Kluwer Academic Publishers, Netherlands.

White, M. L. 1991. Spatial Modelling in Coastal Louisiana, p. 367-376. In S. Mathies (ed.), Data Inventory Workshop, Vol. 5. Louisiana State University and BTNEP, Thibodaux, Louisiana.

White, M. L., J. F. Martin, E. Reyes, G. P. Kemp, J. W. Day, V. Aravamuthan, J. N. Suhayda, and H. S. Mashriqui. 1997. Landscape Simulation Model Upgrading: spatial-ecological modeling of the wetlands of Barataria-Terrebonne. BTNEP Final Report 31. Coastal Ecology Institute, Louisiana State University.

White, M. L., T. Maxwell, R. Costanza, and T. W. Doyle. 1991. Ecosystem Modeling of Barataria Basin, Louisiana: Utilizing Desktop Parallel Technology. Report to the American Water Resources Association. 225-234.